Positive pressure and positive end-expiratory pressure (PEEP)

By Alex Yartsev - 15/06/2015
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Contrary to popular delusion, there are differences between positive airway pressure, positive end-expiratory pressure (PEEP) and CPAP. These terms are not interchangeable and their misuse tends to enrage the ventilation pedant. Once the important distinction between them is well understood, the shared features of these concepts can be explored together. This exploration fits loosely around the CICM Part I syllabus document, where Section F10(i) asks the exam candidates to *"describe the physiological consequences of intermittent positive pressure ventilation and positive end-expiratory pressure"*. As those physiological consequences correlate closely with mean airway pressure and mean airway pressure correlates closely with PEEP, one can draw some sort of connection between the exams and this content. For the purposes of revision, the time-poor candidate can safely ignore the references and limit their reading to the contents of the grey box below.

In brief,

- Positive airway pressure is all respiratory pressure above atmospheric pressure.
- PEEP refers to the positive airway pressure at the end of expiration only.
- CPAP refers to a particular spontaneous mode of ventilation.
- Mean airway pressure is the average pressure on the whole of the respiratory system over the whole of the respiratory cycle.
    - Of the variables which describe positive airway pressure, the variable which has the most impact on the physiological effects of positive pressure ventilation is the **mean alveolar pressure.**
    - Under most normal circumstances, **mean airway pressure correlates well with mean alveolar pressure**, and is usually close to the PEEP value
    - Mean airway pressure differs significantly from mean alveolar pressure when there is significant airflow restriction (eg. bronchospasm) and where there is significant intrinsic PEEP.

As far as published literature on the subject goes, one could not write anything without at some stage mentioning the two articles from 1992 by John Marini

and Sue Ravenscraft. Part I deals with the maths of determining mean airway pressure, and Part II with the significance of this variable. M.J Harrison (1986) offers a discussion of how PEEP and CPAP are different (and similar). Definitions of these terms generally remains unchanged since they were first crafted by the Joint Committee on Pulmonary Nomenclature in 1975. As for the rest of this stuff, most of it is found in basic textbooks, and does not vary dramatically between authors. One may be equally well served by the BASIC manual, *Hess' Essentials of Mechanical Ventilation* (p.132 of the 3rd edition), *Egan's Fundamentals of Respiratory Care* (p. 974 of the 8th edition) or whatever else you've got laying around. Of the officially recommended CICM texts, *Nunn's Applied Respiratory Physiology* (8th ed, p.464-465) touches only briefly on these matters, and likely represents the minimum expected knowledge on this topic.

Airway pressure

An airway disconnected from the corrugated tubing of the ventilator is open to atmospheric pressure. Though used as the "zero" reference point, of course this pressure is not under "zero pressure". A "zero pressure" would be hard space vacuum. The disconnected airway is under atmospheric pressure, around 760 mm Hg or 1033 cm H_2O.

For some reason, we measure gas partial pressure in mmHg, and ventilator gas pressures in cmH2O. In the mercury manometer, pressure which results in the displacement of one millimetre of mercury corresponds to the displacement of 1.36 cm of water in the water manometer.

The tradition of measuring respiratory pressure in terms of water rather than mercury does not appear to have a well-reasoned origin. It may seem to be associated with the use of the bubble PEEP valve (where a positive end-expiratory pressure is generated by submerging the end of the circuit in a tub of water), but the use of water in descriptions of respiratory pressures actually seems to pre-date even this ancient device. Some textbooks (eg. Rhoades & Bell, 4th ed., 2012, p.330) suggest that the respiratory pressure changes are so small that their measurement technique requires a factor-of-ten increase in scale in order to generate conveniently large changes. If one finds oneself

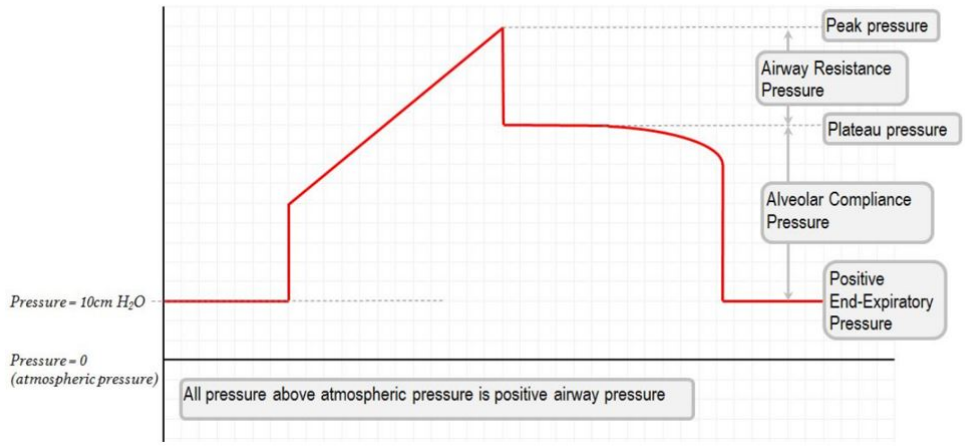
measuring a pleural pressure from a mercury manometer, a change in height of 0.37 mm is much less visible to the naked eye than a change of 0.5 cm H_2O.

This is not a good argument, as a sane person would immediately object to it. Long gone are the days when physiologists would need to squint at menisci in graduated cylinders; this is the era of electronic pressure measurement. The modern intensivist is not at all inconvenienced by small numbers. In any case there is a conceivable range of inconveniently small numbers no matter what liquid is in your manometer, and if convenience was the real issue one could point to the inconvenience of comparing water pressure measurements with mercury measurements of practically every other pressure variable in physiology (gas partial pressure, blood pressure, intracranial pressure, and so on).

So, with the normal" atmospheric pressure of 760 mm Hg, one's entire native respiratory circuit is under 10 metres of water pressure. Similarly, 10 metres below the surface of the sea one's lung experiences an extra 1 atmosphere of pressure, and with deeper submersion, the pressure increases by 1 atmosphere for every 10 metres. Thus, we ventilate our patients with pressure differences which are minute in comparison to the total pressures in play in the environment around them, or even to the pressures in their own cardiovascular system.

Positive airway pressure

Positive airway pressure is any airway pressure above the atmospheric. On the ventilator monitor, airway pressure is offered as a graph of pressure over time. The characteristic pattern of a breath can be seen in the diagram below.



The shape of the pressure waveform is a luxurious banquet of physiological information, and its interpretation is discussed elsewhere. For now, the discussion will be limited to the concepts of PEEP, CPAP, positive airway pressure and mean airway pressure.

Positive end-expiratory pressure (PEEP)

Positive pressure is not PEEP.

But PEEP is positive pressure.

In short, positive pressure is a physical variable which we manipulate to change the gradient of gas flow into (and out of) the patient's lung. PEEP, on the other hand, is Positive End Expiratory Pressure. It is a variable of the 4th phase of ventilation - the pressure at the end of expiration. For a brief precise statement, one may quote the Joint Committee on Pulmonary Nomenclature of the American Thoracic Society and the American College of Chest Physicians (1975), who defined PEEP as

> *"a residual pressure above atmospheric maintained at the airway opening at the end of expiration".*

When we discuss the effects of PEEP, we discuss the effects of positive pressure specifically during the relaxation period of the respiratory cycle; for example, PEEP influences the effort required to generate a breath. In contrast, when we discuss the effects of positive pressure ventilation, we refer to all the effects

which are generated by increased pulmonary and intrathoracic pressure. Positive pressure applied to the respiratory system has numerous consequences ranging far beyond the end-expiratory phase, and these are discussed in subsequent chapters.

Continuous positive airway pressure (CPAP)

CPAP is not PEEP.

CPAP is a mode of ventilation consisting of Continuous Positive Airway Pressure. It is not PEEP, because PEEP is a phase variable of ventilation. CPAP incorporates PEEP (strictly speaking) because at the end of a CPAP breath there is end-expiratory pressure; however CPAP is not synonymous with PEEP, and the two terms cannot be used interchangeably.

One might argue that in any ventilator mode the presence of any PEEP above zero classifies the ventilation as CPAP. Because throughout the respiratory cycle the pressure in the respiratory circuit is continuously above atmospheric, the circuit can be said to be under Continuous Positive Airway Pressure. This is technically correct, but nonetheless confusing. Literary convention has left the two concepts distinct. When discussed in literature, CPAP typically implies a mode of ventilation where the ventilator does not cycle in inspiration, offering only one level of pressure.

In summary, CPAP is a mode of ventilation in which triggering is disabled and the entire respiratory cycle is exposed to a uniform pressure from the ventilator, which corresponds to the PEEP setting. The actual respiratory circuit pressure will vary throughout the cycle because the patient will generate a negative pressure to inhale a breath, and a positive pressure to exhale; but at the end of the breath the pressure will revert to the PEEP setting.

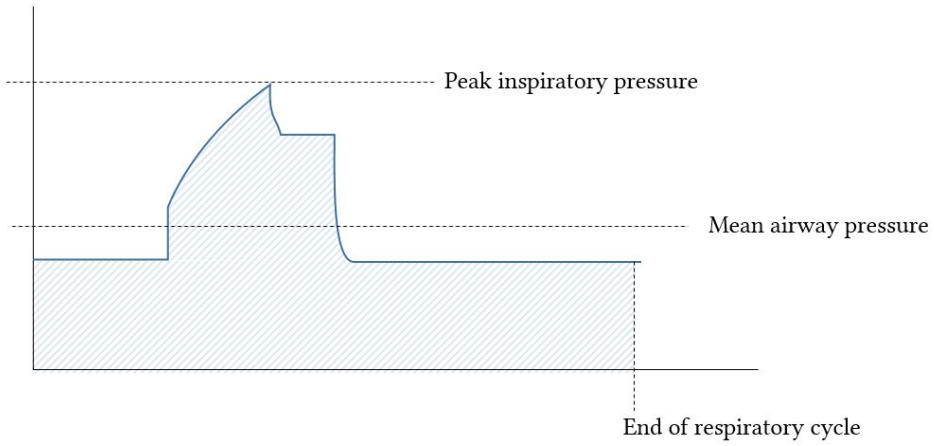
CPAP as a mode of ventilation (along with its advantages and disadvantages) is discussed elsewhere in these chapters.

Mean airway pressure

Mean airway pressure is a fairly descriptive and accurate term. Whenever one finds reference to this variable, it is usually defined as:

> *"the average pressure exerted on the airway and lungs during the ventilatory cycle"*

That comes from Park et al (2016) and Pesenti et al (1985). Basically, one takes the entire respiratory cycle, measures the pressure at regular time points along the whole cycle, then divides the measured pressure by the number of time points. One might even use something like the area under the pressure/time curve.



In most circumstances, because 60-70% of the respiratory cycle is usually spent on not breathing (i.e. at PEEP), the mean airway pressure is relatively close to PEEP.

Mean airway pressure is affected by many variables in mechanical ventilation:

- Inspiratory pressure
- PEEP and auto-PEEP
- I:E ratio
- Inspiratory pressure waveform

Whenever one has relatively normal airway resistance, mean airway pressure variable closely approximates mean alveolar pressure. The closer it approximates mean alveolar pressure, the more relevant it becomes – mean alveolar pressure is the pressure which determines the respiratory and haemodynamic effects of ventilation. In virtually all normal scenarios, one can safely say that all the pressure-related physiological effects of mechanical

ventilation correlate with the magnitude of mean airway pressure.

This relationship breaks down when there is severe bronchospasm.

- When there are high peak airway pressures due to high airway resistance, the ventilator's measurement of mean airway pressure becomes increasingly inaccurate because it also measures the pressure generated by flow against airway resistance. As a result, measured mean airway pressure will overestimate mean alveolar pressure when there is severe bronchospasm
- When there is an excessive intrinsic PEEP, the measured mean airway pressure may underestimate true mean alveolar pressure. Valta et al (1996) found that at an intrinsic PEEP of 10 cm H2O, the mean airway pressure underestimated mean alveolar pressure by about 50%.

Previous chapter: Alarms and safety features in mechanical ventilation

Next chapter: Intrinsic PEEP and positive pressure ventilation

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References

Pesenti, Antonio, et al. "Mean airway pressure vs. positive end-expiratory pressure during mechanical ventilation." Critical care medicine 13.1 (1985): 34-37.

Park, Jin Ha, et al. "Effect of the prolonged inspiratory to expiratory ratio on oxygenation and respiratory mechanics during surgical procedures." Medicine 95.13 (2016).

Stewart, A. R., N. N. Finer, and K. L. Peters. "Effects of Alterations of Inspiratory and Expiratory Pressures and lnspiratory/Expiratory Ratios on Mean Airway Pressure, Blood Gases, and Intracranial Pressure." Pediatrics 67.4 (1981): 474-481.

Marini, JOHN J., and Sue A. Ravenscraft. "Mean airway pressure: physiologic determinants and clinical importance--Part 1: Physiologic

determinants and measurements." Critical care medicine 20.10 (1992): 1461-1472.

Marini, JOHN J., and Sue A. Ravenscraft. "Mean airway pressure: physiologic determinants and clinical importance--Part 2: Clinical implications." Critical care medicine 20.11 (1992): 1604-1616.

Valta, Paivi, et al. "Mean airway pressure as an index of mean alveolar pressure." American journal of respiratory and critical care medicine 153.6 (1996): 1825-1830.

Duncan, A. W., T. E. Oh, and D. R. Hillman. "PEEP and CPAP." Anaesthesia and intensive care 14.3 (1986): 236-250.

Harrison, M. J. "PEEP and CPAP." British medical journal (Clinical research ed.) 292.6521 (1986): 643.

American College of Chest Physicians. "Society of Thoracic Surgeons. Pulmonary terms and symbols: a report of the ACCP-STS Joint Committee on Pulmonary Nomenclature." Chest 67 (1975): 583-93.

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